Quantification of Spatial Heterogeneity in Old Growth Forests of Korean Pine[1]

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Abstract Spatial heterogeneity is a very important issue in studying functions and processes of ecological systems at various scales. Semivariogram analysis is an effective technique to summarize spatial data, and quantification of spatial heterogeneity. In this paper, we propose some principles to use semivariograms to characterize and compare spatial heterogeneity of ecological systems and use an example of old growth forests of Korean pine to demonstrate these principles and to discuss its characteristics of spatial heterogeneity.

Key words: Spatial heterogeneity, Semivariogram, Korean pine, Landscape ecology.

Introduction

Spatial heterogeneity(SH), which is generally defined as the complexity and variability of a system property(e.g., vegetation type, population density, plant biomass, soil nutrients) in space, is of great interest to ecologists studying functions and processes of ecological systems at various scales (Risser et al 1984, Turner 1987, Turner et al 1991, Kolasa et al 1991). However, quantitative analysis of spatial heterogeneity is a very impotence in ecological system and landscape studies(Li et al 1995, Weine 1992). From the studies of spatial heterogeneity, we can get the degrees and changes of spatial heterogeneity in different scales, and understand the complex processes and feedback in ecosystems and landscapes(e.g., Moloney et al 1991).

Li et al(1995) defined two approaches for analyzing heterogeneity in landscapes: spatial characterization and spatial comparison. Spatial characterization involves the use of mathematical descriptors, e.g., semivariograms, information indices, and fractal, to quantify the spatial variability of some properties of landscapes. Spatial characterization is useful to detect patterns, i.e., degrees of spatial heterogeneity and changes in spatial heterogeneity over varying spatial scales. This information, coupled with observations and ecosystem models , can be useful to interpret observed patterns and their effects on functions and processes of ecological systems. Spatial comparison, on the other hand, involves the use of mathematical descriptors to quantify and compare the same variability of landscape properties in the following ways: 1)between the same variable at different sampling times to detect changes in a system,2)between the same variable at different sites to contrast different systems, and 3)between different variables at the same site to establish relationships.

Korean pine(*Pinus koraiensis*), which often mixed with hardwoods, typical old growth forest ecosystem, is a main important species in Northeast part of China. Korean pine forests is high degrees of spatial heterogeneity in landscape, which controlled the function and processes of ecosystem in spatial and temporal. In this paper we use the quantitative method of semivariogram analysis, both spatial characterization and spatial comparison, to discuss the spatial heterogeneity of old growth forests of Korean pine.

Semivariogram analysis is based on the theory of regionlizaed variables, and it examines spatial variation and correlation of natural phenomena (Mtheron 1963, Journel et al. 1978, Weester 1985, Cressie 1991). While recent applications of semivariogram analysis in ecological research have

demonstrated its effectiveness to summarize spatial data(Robertson 1987, Robertson et al 1988, Palmer 1988, Fortin et al 1989, Legendre et al 1989, Levin et al 1989, Rossi et al. 1992).In this study, we propose some

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principles for ecological interpretations of semivariograms (i.e., spatial characterization) and a method to compare two spatially autocorelated variables (i.e., spatial comparison) through the example old growth forests of Korean pine.

Study Site and Data

The study site is the old growth forests of Korean pine, at the Liangshui Natural Reserve of Xaoxingan Mountains, in Northeast parts of China. It is a typical forest vegetation and landscape in this region(Wang et al 1996, Li et al 1993). The total area of Liangshui natural reserve is about 6394 hm^2, most stands are mixture between conifer(e.g., pine, spruce, and fir) and hardwoods (e.g., ash, birch, oak, aspen, maple, basswoods, walnuts). There are twelve forest stand types(Li et al. 1993), which age range distribute from 200 to 300 years, based on the composition of dominant species.

The size for this study is 144 hm^2, located in undisturbed old growth stand of Korean pine. We established 12 transects from south direction to north, and set up 12 plots in each transects. The total numbers of plots is 144 and each plot size is 30 × 30m. The sampling interval between transects, between plots are 100m (Fig.1). In each plots, we measured and named each trees, height, DBH, base area, age, cover rate, densities, soil, and plants.

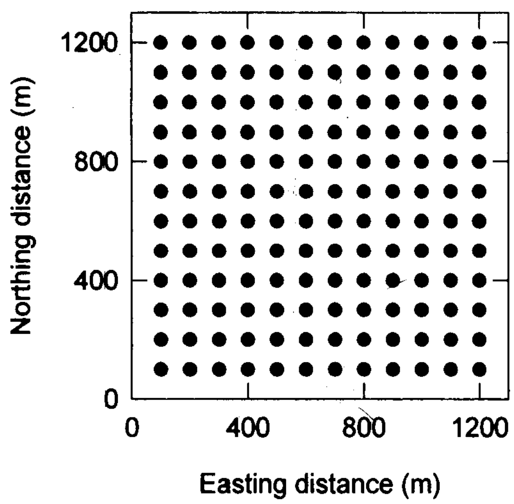

Fig.1. Diaram of plot locations sampled in the old growth forests of Korean pine

In datasheet from 144 plots, we use both base area and age to be as variables to analysis variation of korean pine in apace, and use geostatistics(Journal et al 1978, Weberst 1985, Isaaks et al 1989) to established semivatiogram models and make data analysis. Semivariogram analysis is the effectiveness to summarize spatial data. For the characterization of spatial heterogeneity, the parameters of semivariogram, range(a), sill(C+Co), nugget variance(Co), and fractal dimension(D) are useful tool for quantification of spatial heterogeneity and can be derived from semivariograms. The first three parameters are traditionally used in semivariogram analysis (e.g., Journal et al 1978, Weberst 1985). Using the concept of scale and semivariogram (e.g., Trangmar et al 1985, Burrough 1987), we may decompose the spatial heterogeneity of numeric variable into two quantifiable components: SH=SH(autocorr)+SH(random)(Fig. 2).

This decomposition can help us to understand the true of spatial heterogeneity by mean of semivariograms(Li et al 1995). The fourth parameter, fractal dimension is determined from the relationship between semivariance and lag distance(h) (Burrough 1983,1986). In addition, we also can use anisotropy ratio K(h)to characterize anisotropic structure of variation in space. For the comparison of spatial heterogeneity, standardized semivariograms SS(h) can be used to compare different variables in landscapes. Finally, we use Kriging maps(Issaks et al 1989) to show the spatial pattern of korean pine in sampled area.

Results and Discussion

Results

The variables of base area and age of korean pine were examined by semivariogram analysis. Values of the four semivariogram parameters and fitting models are given in Table 1. For each variable, the isotropic semivariogram(Fig.3), two anisotropic semivariograms were constructed(Fig.4a and 4b). The two perpendicular directions used in anisotropic semivariograms coincide with the major environmental gradients: θ_1=0 (west to east, i.e., elevation is commonly the same) and θ_2=90 (south to north,i.e., elevation is from 320m to 360m). The anisotropy ratio is illustrated in Fig.4c, and the standardized semivariograms Of the two maps are displayed in Fig.5. The Kriging maps of bases area and age are illustrated in Fig.6.

Table 1: Parameters of semivariograms and fitting models for base area and age of Korean pine forests.

Variables	Mode #	Co	C0+C	Co/Co+C	a	D	RSS	R^2
Bases area	S	35.9	74.75	0.480	468	1.887	233.49	0.768
Age	L	5493.0	11750	0.467	993	1.857	4800	0.980

:S=spherical model; L=linear model.

Discussion

In an "ideal" semivariogram, r(h) increase with h, the sill is an approximation of the maximum variance of the variables. The curve shapes of semivariograms(Fig.3)

show that spatial heterogeneity varies significantly in Korean pine stands. The ranges of bases area and age are 468 m and 993 m respectively. Its represents the distance beyond which the stands of Korean pine are no longer correlated in space. The nugget variance, non-zero values, expresses the discontinuous variations of a stands at small scale.

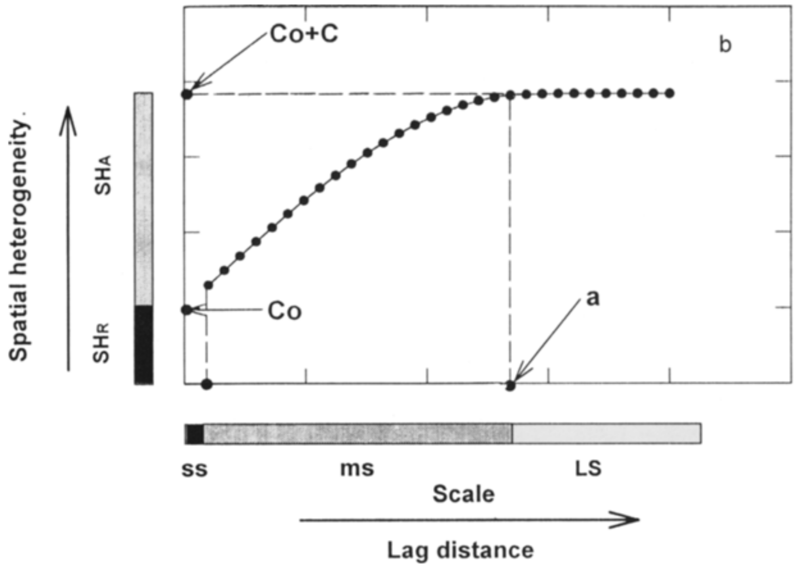

Fig. 2. Semivaiograms and their parameters(a), decomposition of spatial heterogeneity over scales where ss stands for small scale, ms for mediumscale, and Ls large scale(b)

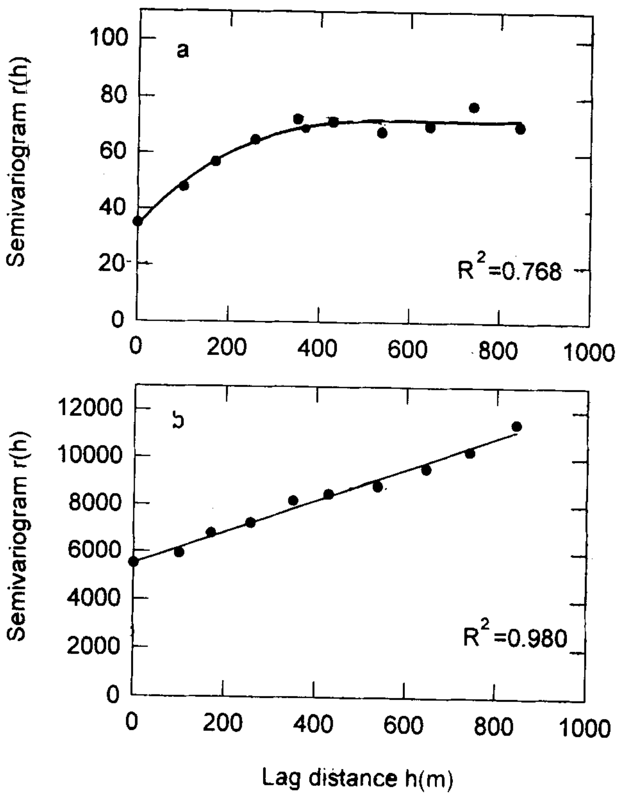

Fig. 3 The isotropic semivariograms of bass area(a) and age(b) of korean pine

There are a stronger anisotropic structure beyond lag distance 400m (Fig.4a and 4b), and significant spatial heterogeneity between the two directions. Anisotropy ratio is above the isotropic line over 400m of the scales(Fig.4c). This means that spatial variation of the stands is anisotropy beyond 400m, and it is isotropic variations from zero to 400m.

The degrees of spatial heterogeneity changed when different components are examined(Table 1). High sill means high degrees of spatial heterogeneity. The nugget variance to sill ratio (Co/Co+c)show that the spatial heterogeneity of random are 48% and 46.7%, and of autocorrelation are 52% and 53.3% , respectively, for both variables in stands.

SH(autocorr) is the autocorrelated variation and exists at medium scales and is defined by semivariograms within the range of spatial correlation. It is random, but is spatially correlated and change with scale. SH(random) usually occur at small scales, and independent and unknown. We define it as the sum of variations within the scale less than the minimum resolution of observations. Thus, SH(random) can be represented by the nugget variance. High nugget variance to sill ratio means high degrees of SH(random). Fractal values are 1.887 and 1.857 indifference due to the Co/Co+C sameness. On the other hand, the isotropic standardized semivariograms (Fig.5), using to compare different variables, display the spatial autocorrelations. These results indicate that SH(autocorr) is dominant in stands of korean pine.

Spatial heterogeneity determine the characteristics of spatial pattern in ecological systems. In the block kriging maps based on the semivariogram models(Table 1), we can see clear spatial pattern of Korean pine(Fig.6a) and

its age(Fig.6b).

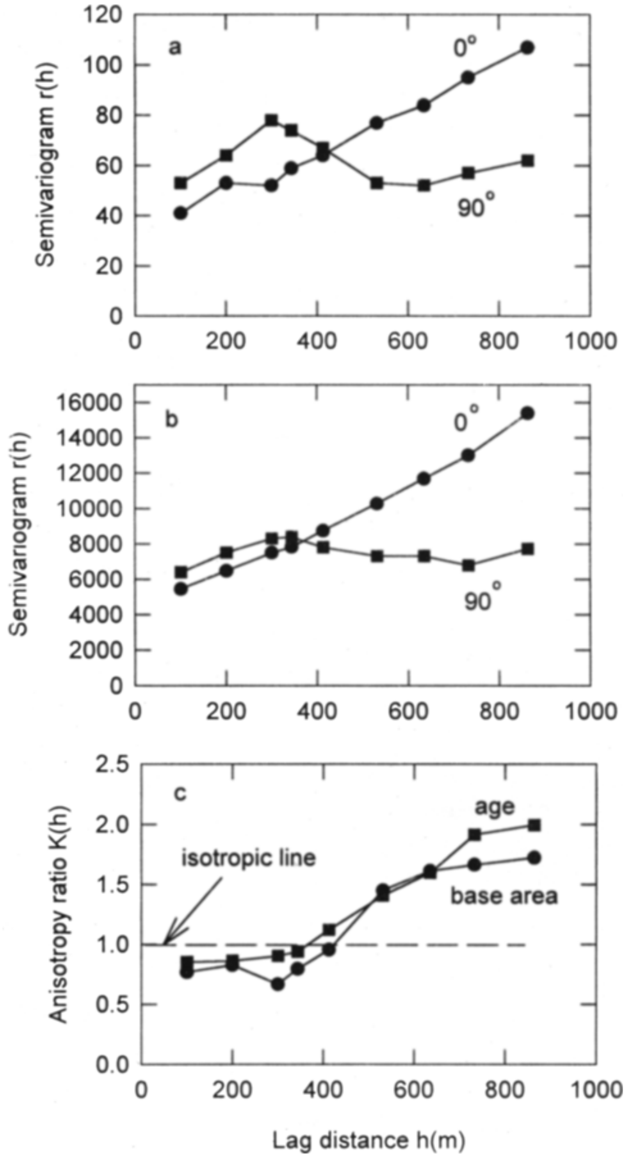

Fig. 4. Anisotropic semivariograms of base area (a), age(b) and anisotropy ratio(c)

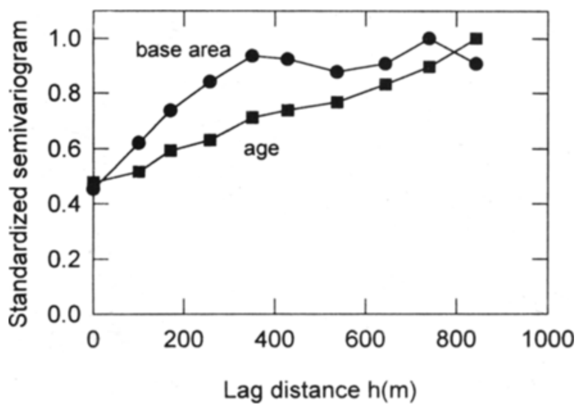

Fig. 5. Standardized semivariograms of base area and age

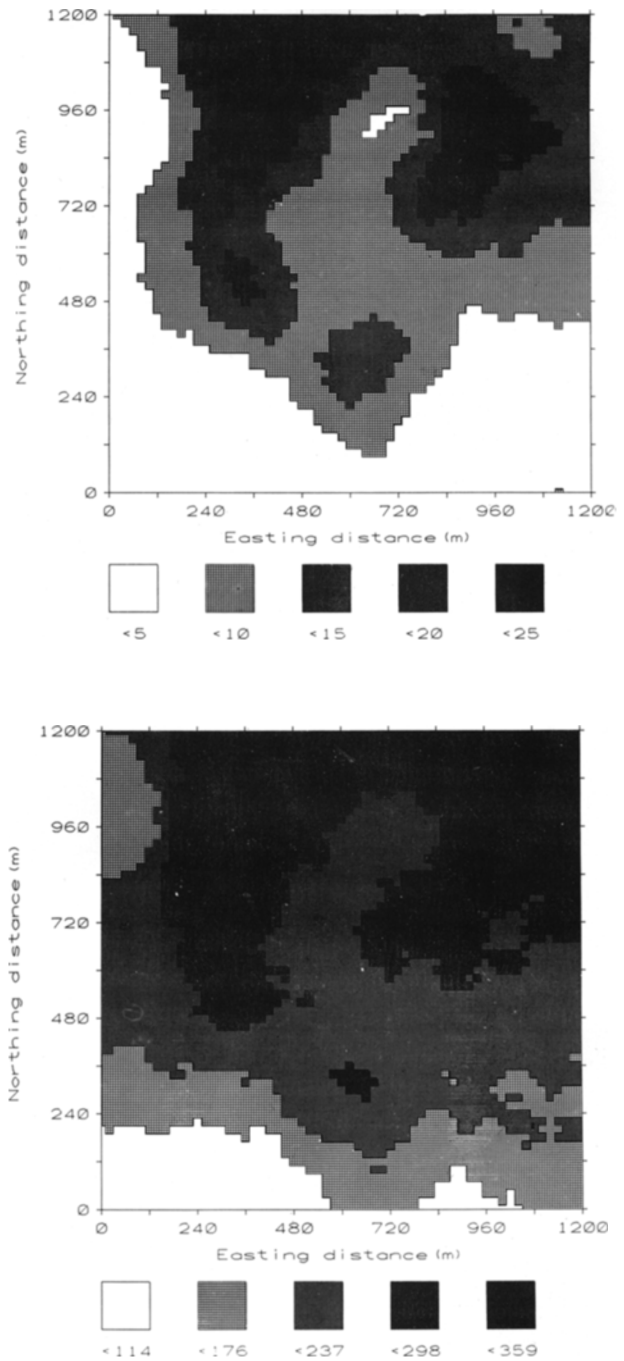

Fig. 6. Kringing maps of base area(a) and age (b) of old growth forest of korean pine

In south site stands, there are few Korean pine trees with small age, and there are more Korean pine trees with high age in the north site stands. Comparing both kriging maps, the patterns of base area and age are close

on each other. Spatial variability was high and control the ecological functions and processes of stands.These patterns are quantitative. The size and shape demonstrated that spatial heterogeneity in old growth forests of Korean pine is very important in forest ecosystems.

Conclusion

Spatial heterogeneity is of a very important issues and of great interest to ecologists studying functions and processes of ecological systems at various scales. Quantitative approaches are vital to further development of spatial heterogeneity(Wiens 1992). In this paper, we emphasize quantitative analysis of spatial heterogeneity and use method of semivariogram analysis, which is effectiveness tool, to study spatial heterogeneity in old growth forest of Korean pine. The results show that there are high degrees of spatial heterogeneity in Korean pine forests, which changed with scales and directions. The need to establish relationships between landscape structure, processes and ecosystem management of Korean pine forests merits more quantitative studies of spatial heterogeneity.

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Site Quality Evaluation for Mixed, Uneven-aged, Natural Forest Dominated by Korean Pine in Northeast China[1]

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Abstract Six site types of Korean pine(*Pinus koraiensis*) forest, Mongolian oak type, Yezo spruce type, Korean spruce type, Amur linden type, Ribbed birch type and Manchurian ash type, are easily found on the south slope of Xiaoxing'an Mountains. The analysis results of H-A and H-Dbh relationships by site type showed that height growth of Korean pine dominant or codominant stems in natural stands is not directly related to its age but is directly related to its diameter, which closely accords with the Chapman-Richards equation(Relativity coefficients more than 0.8668). A method for evaluating site quality using height and diameter of dominant or codominant tree independent of tree age is examined. There are significantly differences in site quality of Korean pine among six site types above. The site index was highest on Manchurian ash type, and lowest on Mongolian oak type. Differences of site index with a reference dbh of 40 cm between highest and lowest sites can reach 11 m in maximum., 7 m in average, respectively. Other rationales of the H-D method were discussed.
Key words: Korean pine, Uneven-aged forest, Site index, Site quality evaluation

Introduction

Site index is a convenient step toward the ultimate goal of predicting the production capability of forest land, and it is a useful direct measures for a potential expectation paradigm in terms of site quality. Traditionally, the calculated value of the tree height at that reference age is the site index, but, height at a particular age for a gap regeneration tree species in uneven-aged stands often has little biological significance. Because of problems with height-age relationships in uneven-aged stands, some researchers developed site index using diameter instead of age[6-8].

Korean pine mixed forest, covered from Changbai Mountains to Xiaoxing'an Mountains in northeast China, is a very uneven-aged forest community. The site types may be easily classified, based on its coexisted tree species composition, Ma Jianlu (1994) classified Korean pine forest in the south slope of Xiaoxing'an Mountains into six site types. They are Mongolian oak(*Quercus mongolia*) site type (MOST), Yezo spruce (*Picea jezoensis*) site type (YSST), Korean spruce (*P. koraiensis*) site type (KSST), Amur linden (*Tilia amurensis*) site type(ALST), Ribbed birch(*Betula costata*) and Manchurian ash (*Fraxinus mandchurica*) site type(MAST)[1]. However. the site quality evaluation is failure because the effective evaluation indices had been found up to now.

The objective of this study was to develop an indicator of site productivity for the predominately mixed, uneven-aged, natural stands found in northeast China.

Methods

From 1990 to 1993 a stratified, 257 temporary plots were established at Dailing, Haolianghe, Meixi, Cuiluan and Wuying in the south slope of Xiaoxing'an Mountains. Dominant or codominant Korean pine stems in each 40 × 50 m plots were measured for total height(m), dbh (diameter at breast height(cm) and age (Table 1).

The guide curve method was used to generate anamorphic site index equations on each site type. A comparison method of site- to- site in site index was used for site quality evaluation.

Results and Analysis

Site index expression

Height-age relationship in Korean pine dominant stems Height growth of Korean pine is not directly related to its age because of stand structure and dynamics. There are significant differences of measured height

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at the same age class (each 20 years), and of measured age at the same height class (each one meter)even on each site type (Table 2 and Table 3). For example, on Amur linden site type, the height value of Korean pine dominant or codominant stems changes from 13.7 m to 2.6 m within 20 years, and age value varies from 130 years to 30 years within one meter height. Such the differences are forced to give up the possibilities to use height-age relationship to evaluate site quality for Korean pine forest.

Table l. Summary statistics by site types for the 257 temporary plots with dominant or codominant Korean pine stems

Variable	Minimum	Mean	Maximum
MOST(N=22)			
Age(years)	115	194	290
Height(m)	16.1	22.3	26.4
Dbh(cm)	25.6	43.3	69.3
YSST(N=29)			
Age(years)	157	201	260
Height(m)	19.5	24.8	28.9
Dbh(cm)	27.0	45.4	60.5
KSST(N=45)			
Age(years)	91	185	310
Height(m)	18.0	25.9	31.8
Dbh(cm)	24.0	44.9	80.0
ALST(N-81			
Age(years)	60	202	325
Height(m)	16.0	26.2	31.8
Dbh(cm)	20.0	44.4	88.0
RBST(N=58)			
Age(years)	81	228	412
Height(m)	23.0	30.2	36.1
Dbh(cm)	24.3	60.5	92.0
MAST(N=22)			
Age(years)	107	166	200
Height(m)	24.3	29.0	33.1
Dbh(cm)	26.8	45.5	65.7

Height-dbh relationship in Korean pine dominant stems Generally, there is a direct relationship between height growth and diameter growth of tree species whether in even-aged stands or in uneven-aged stands. Height-dbh relationships of Korean pine in six site types above closely accord with the Chapman-Richards function with more than 0.8668 relativity coefficient (Table 4).

The analysis above show that height growth of Korean pine dominant or codominant stems in natural stands is not directly related to its age but its diameter, which closely accords with the Chapman-Richards function. So, age factor is eliminated, and the site index is yet interpreted as the calculated value of the dominant tree height at that reference dbh to evaluate site quality for Korean pine natural forest.

Table 2. The differences of height for Korean pine by age classes(m)

Age(years)	MOST	YSST	KSST	ALST	RBST	MAST
161-180	3.6	-	-	-	-	-
181-200	-	-	-	-	-	6.8
201-220	9.4	5.0	10.6	12.5	7.8	2.2
221-240	1.2	2.4	7.9	6.5	7.8	8.8
241-260	7.8	6.5	8.0	13.7	8.5	4.1
261-280	-	6.0	10.8	9.6	10.3	-
281-300	6.3	3.4	-	6.6	7.0	-
301-320	-	2.0	3.4	3.4	6.9	-
321-340	-	-	-	2.6	4.7	-
341-360	-	-	-	4.4	4.7	-
361-380	-	-	0.3	-	-	-
381-400	-	-	-	-	-	-
401-420	-	-	-	-	2.3	-

Table 3. The differences of age for Korean pine by height classes (years)

H.(m)	MOST	YSST	KSST	ALST	RBST	MSST
20	81	-	-	-	-	-
21	-	-	59	126	-	-
22	-	47	59	130	-	-
23	50	24	3	31	19	-
24	-	-	-	65	-	58
25	35	60	65	42	50	-
26	130	59	122	86	69	-
27	-	37	74	30	2	19
28	-	60	27	97	-	-
29	-	-	71	58	88	27
30	-	-	7	83	82	58
31	-	-	18	55	143	60
32	-	-	90	48	106	-
33	-	-	-	-	114	30
34	-	-	-	-	110	
35	-	-	-	-	55	

Table 4. The coefficients of Chapman-Richards equation of height variation with dbh for Korean pine by site types

Site type	A	B	K	RD
MOST	28.58903	1.210121	0.03814453	0.9958
YSST	28.89749	1.630860	0.05500559	0.8668
KSST	33.38450	0.921017	0.03320438	0.8990
ALST	33.53536	1.144548	0.03994221	0.9345
RBST	42.26388	0.407044	0.01011532	0.9427
MAST	42.73645	0.382198	0.01036132	0.9770

Site quality evaluation

Different growth process of height by dbh among the six site types of Korean pine forest (Table 4) implies that there are significantly differences in site quality among the types. The average site index with a reference dbh of 40cm on each site type may be calculated using the parameters in Table 4 (Table 5), and site index curves for Chapman-Richards equation with the parameters in Table 4 may be made (Figure 1).

Table 5. The average site index calculated by site types(m)

MOST	YSST	KSST	ALST	RBST	MAST
21.3	23.7	25.1	25.9	27.0	28.3

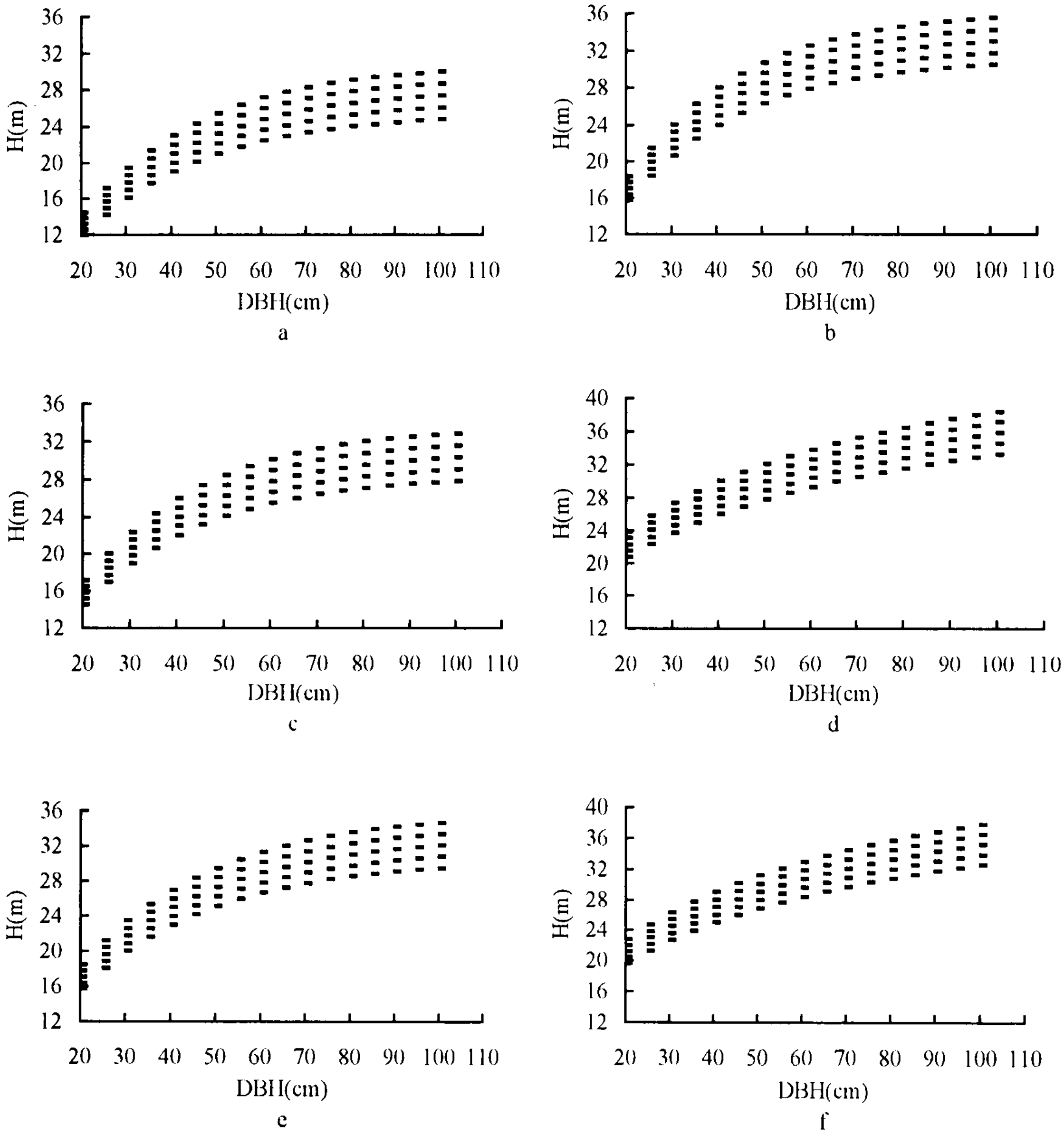

Fig. 1. Site index curves of Korean pine by site types

a--Mongolian oak site type; b--Amur linden site type; c--Yezo spruce site type
d--Manchurian ash site type; e--Korean spruce site type; f--Ribbed birch site type

Among the six site types, site index was highest on Manchurian ash type, and lowest on Mongolian oak type. Differences of site index between highest and lowest sites can reach 11 m in maximum, 7m in average, respectively.

Conclusion and Discussion

The analysis results of H-A and H-Dbh relationships showed that height growth of Korean pine dominant or

codominant stems in natural stands is not directly related to its age but is directly related to its diameter, which closely accords with the Chapman-Richards function. So, age factor is eliminated, and the site index is yet interpreted as the calculated value of the dominant tree height at that reference dbh of 40 cm to evaluate site quality for Korean pine natural forest.

Site quality of Korean pine are significantly different among sites. Among the six site types, site index was highest on Manchurian ash type, and lowest on Mongolian oak type. Differences of site index between highest and lowest sites can reach 11 m in maximum, 7m in average, respectively.

Each tree growth is expressed by H=H (t), D=D(t). If either component $H'(t) \neq 0$, or $D'(t) \neq 0$, say $D'(t) \neq 0$ during the growing season, it implies that D=D (t) is an invertable function; thus, t=t (D). H=H (t) therefore may be written $H=H(t(D))=\varphi(D)$, and time is eliminated from the argument. So, site index also may be interpreted as the value of the tree height at that reference diameter.

Diameter growth is considered more sensitive than height growth to environmental factors[5], yet foresters traditionally refrain from using diameter for site estimation due to its dependence upon stand density. Recent studies suggest that yield per unit area, irrespective of initial density, tends to converge in time[2-4]. Assuming forest stands conform to a similar "law of constant yield", the influence of stand density on potential productivity assessment may be overrated and diameter may be used with height to evaluate potential productivity.

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